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# The potential for sustainable biomass in the Romanian energy sector. Value chain analysis for potential black pellets investments

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***Abstract.*** *A value chain analysis was conducted to assess the potential of substituting coal with black pellets for energy production in Romania, including an evaluation of feedstock availability. The biomass production landscape in Romania is evolving due to rising demand and a growing number of pellet producers competing for raw materials. This shift is also driven by a decline in wood processing and exploitation activities, primarily due to reduced access to forest resources, legislative instability, and administrative complexities. Romania harvests 19 million cubic meters of wood annually, utilising only 50% of its sustainable harvesting capacity, which is equal to the natural growth rate of its forests. The operational costs for the value chains involved in power generation from black pellets and coal in a 50 MW power plant were also estimated. For the black pellets value chain, the annual operational costs are approximately 100.68 million lei–more than five times higher than the estimated 18.18 million lei for coal. This significant cost difference arises from higher expense of biomass harvesting compared to coal mining. The black pellets value chain also involves biomass pretreatment and steam explosion processes, which require electricity for feasibility. Additionally, the higher ash content of coal could increase the overall expenses due to ash disposal costs, although these costs were not included in this analysis.*

**Keywords:** Biomass, value chain, coal, energy production, power plant, operating cost.

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## Introduction

The black pellet manufacturing industry has advanced significantly in recent years and has emerged as a viable alternative to the conventional use of forest products. This shift is driven by the benefits of using value-added forest and agricultural products, alongside reliable and efficient waste management practices. Black pellets contribute to energy security by utilising low-cost feedstocks, such as waste materials, for their production. This reflects both market-driven behaviour and politically motivated efforts to reduce emissions (Dudau & Nedelcu, 2016). Moraru (2015) emphasizes these benefits as essential for harmonising advantages within the renewable energy sector. The high energy efficiency of black pellets is due to their high density, heating value, and low moisture content, which also results in reduced storage and transportation costs (Andersone et al., 2021). As a result, black pellets have become increasingly relevant for both residential and industrial applications, providing a sustainable and efficient solution for heat and energy production.

The concept of the value chain was first proposed by Porter (1985), who defined it as a sequence of essential activities within an organisation that generate value for a product or service. The value chain provides a strategic framework for analysing the activities involved in any business, allowing the assessment of their relative cost and role in differentiation. Specifically, it represents the total value of a firm and consists of both value activities and margins. Value activities are the distinct physical and technological tasks a firm performs, that is, the building blocks by which it creates products of value to buyers. According to Porter, the margin is the difference between the total value and the combined cost of performing these activities (Porter, 1985). Value chain analysis is particularly useful for evaluating new technologies, methods, or products across various fields, as demonstrated in recent biomass research (Caporusso et al., 2022).

Heat production from biomass has historically been significant for Romania, and its role in the energy market is expected to grow as the country adapts its energy strategy to incorporate biomass utilisation (Clodnițchi & Chinie, 2015). Assessing the potential benefits of utilising black pellets in Romania will contribute to this ambition. Existing value chain analyses primarily focus on specific locations, production sites, and products, which account for local factors that critically influence performance. For instance, assessments of wood pellet value chains have been conducted in Sweden (Hansson et al., 2015) and of the maritime supply chain for wood pellet distribution in Norway (Andersen et al., 2017). However, to the authors' knowledge, no value chain analysis of black pellets utilisation for energy production has been performed for Romania. Therefore, the primary objective of this paper is to conduct a value chain analysis to evaluate the potential of substituting black pellets for coal in energy production within Romania. The secondary objectives include:

- An overview of feedstock availability in Romania for black pellets production.
- A comparative analysis of operational costs for using black pellets versus coal in energy production.

Due to the increasing demand for renewable energy sources, the market for black pellets has expanded significantly and placed substantial pressure on the supply side. From 2018 to 2022, the European biomass pellet industry experienced a compound annual growth rate (CAGR) of 5.8%, with projections indicating a 6.9% CAGR through 2033 (Future Market Insight, 2024). This heightened demand has led to the establishment of more black pellet production facilities, all competing for a limited supply of wood resources. Considering the scarcity of wood and agricultural materials, combined with increased competition, these production facilities have continually optimised their production, logistics, and sales operations to maintain their market shares.

The value chain activities are divided into two main categories: primary and support activities. Primary activities involve the physical creation of the product, its marketing, sale, transfer to the buyer, and post-sale support. These include inbound logistics, operations, outbound logistics, marketing and sales, as well as customer service. The value chain tracks all the activities within a firm that contribute to the development of a product or service, from its initial conception to its final, value-enhanced form as it progresses through the supply chain.

The basic idea is that each component within the value chain adds value that exceeds its associated costs, ultimately generating a positive net revenue. Therefore, maximising profit can be achieved by increasing the value added at each stage of the supply chain while simultaneously minimising costs. This value chain concept extends beyond internal operations to include external factors, such as suppliers and distributors, as well as the relationships among these activities. Additionally, competition can influence the dynamics and effectiveness of the value chain. A competitive advantage can be achieved by reducing costs or optimising the value chain itself. Importantly, value chains vary significantly across firms and industries, reflecting their unique operational needs and market conditions.

The supply chain refers to a network of suppliers and distributors involved in moving raw materials through production processes to final customers. In contrast, the value chain refers to a set of internal processes and activities within a company or sector that adds value to a product or service, encompassing both primary and support activities related to production, distribution, and usage. While the terms 'supply chain' and 'value chain' are often used interchangeably in the literature (Joonkoo, 2016; Henderson et al., 2002; Lee, 2010; Sturgeon, 2001), they refer to distinct processes. The supply chain refers to a series of firms or agents, each with their own value chain, that collectively move materials forward and deliver products and services to customers. In contrast, the value chain emphasises internal activities that enhance the value of the product or the service.

Value chain optimisation is realised when a company's manufacturing functions within the supply chain are effectively integrated and coordinated through appropriate operational management strategies. This integration significantly boosts the overall supply chain efficiency. As a result, more efficient management of distribution channels, sustainable operations, advanced long-term forecasting, and streamlined operational practices within the black pellet supply chain further optimise the value chain. To achieve these outcomes, a variety of supply chain management strategies should be employed and continuously refined. Additionally, exploring and implementing various modelling techniques will help identify the most effective approach for managing the black pellet supply chain in the face of evolving market conditions.

In this paper, we describe the challenges associated with the value chain analysis of a typical black pellet production facility. The black pellet production process involves several key steps: drying, grinding, conditioning, pelletising, screening for fine separation, and packaging/storing the final product. The primary raw material for black pellets is wood, particularly wood shavings and sawdust from the wood processing industry. However, other sources of woody biomass, such as mill waste, urban clearing, harvest residuals, and roundwood, can also be used. This biomass is often supplemented with agricultural materials. The latest technologies enable the production of one ton of pellets from approximately 7.5 $m^3$ of sawdust with a moisture content ranging from 7% to 10%.

The wood pellet value chain begins with the harvesting operation at the forest landowner's site. This initial step is crucial for securing a sufficient supply of wood fibre and assessing the transportation costs associated with moving the biomass from the harvesting location to the production facility. After production and cooling, the pellets can be packaged in small bags for residential customers, large containers for industrial clients, or stored in bulk within silos or industrial storage facilities. The primary costs associated with black pellets are the raw materials and the drying process, while maintenance and storage costs remain relatively low.

In terms of policy implications, clear sustainability standards are essential to ensure that biomass sourcing does not contribute to deforestation or harm biodiversity. Achieving this goal can primarily be accomplished through certifications for sustainable forestry. Additionally, funding and tax incentives to promote research in advanced black pellet technologies would improve efficiency and cost-effectiveness. A robust regulatory framework is also crucial for addressing the environmental impacts and conducting lifecycle assessments of black pellet production and usage.

Facilitating market access for black pellets through government subsidies can support the transition away from fossil fuels, encouraging the gradual replacement of coal with black pellets in coal-dependent regions. This shift would reduce greenhouse gas emissions, address misconceptions about biomass energy, and promote awareness of sustainable practices for a cleaner environment. International collaboration among national policymakers on biomass standards could harmonise efforts, enhance policy effectiveness, and advance sustainability goals. Additionally, integrating black pellet technology with other renewable sources can diversify energy portfolios and strengthen energy security. Robust environmental monitoring systems are also crucial for ensuring transparency and building public trust in these initiatives.

## Potential black pellets investments in Romania

### *Romanian biomass providers for black pellet producers*

In Romania, black pellets producers fall into three main categories:

1. Integrated producers: These bulk producers primarily utilise wood residuals, particularly sawdust, as their main raw material for pellet production.
2. Standalone producers: These producers buy sawdust and wood from external suppliers, often located in areas such as Suceava County. They are willing to pay premium prices for raw materials, such as sawdust and wood leftovers, due to the significant added value created in their production process.
3. Agro pellet producers: Specialising in agricultural pellets, these producers use materials like straw and corn cobs. Agro pellets have higher silicon content, making them unsuitable for household use due to excessive ash production.

The biomass production landscape in Romania has become increasingly competitive due to the rising demand and a growing number of pellet producers contending for raw materials (Moiceanu et al., 2023). This shift is further driven by a decline in wood processing and exploitation activities in recent years, largely due to reduced access to forest resources, legislative instability, and bureaucratic hurdles.

Utilising biomass for electricity production depends on the use of certified biomass, which presents significant challenges. Certifying forest-harvested biomass is complex and ensuring traceability while maintaining accurate records of its origin can be equally difficult. The introduction of price caps has led some producers to shift their focus toward international markets. Additionally, the instability in legislative and fiscal frameworks has compelled producers to diversify their distribution channels, both domestically and internationally, as a precaution against potential disruptions in an unpredictable environment.

Currently, the residential pellet consumption market in Romania includes approximately 90,000-100,000 households, each with an average annual consumption of 3 tons. Additionally, around 100,000 semi-industrial consumers, such as farms and bakeries, use black pellets for commercial purposes.

Romania officially harvests 19 million cubic meters of wood annually, utilising only 50% of its sustainable exploitation rate, defined by the natural growth rate of its forests. In contrast, Nordic countries and Germany operate at approximately 95% of their sustainable potential (Banacu & Cioran, 2023). However, the issue of illegal logging remains highly debated. According to the Ministry of Environment's European Semester Report from 2020, illegal logging causes annual losses of around 6 billion EUR (European Commission, 2020).

With the upcoming introduction of financial incentives for forest owners to preserve their woodlands through carbon credits, fewer forest owners are expected to engage in wood harvesting. Additionally, a significant challenge in black pellet production is the accessibility of biomass sources, which is heavily influenced by the existing road infrastructure.

### *Overview of feedstock availability in Romania*

This analysis focuses on the production of black pellets from sawdust derived from woody biomass, referred to as 'wood' throughout the report. Table 1 shows the available forest stock and the removal of roundwood in Romania (Bioenergy Europe, 2019).

*Table 1. Available stock of forest and removal of roundwood in Romania*

| **Available stock of forest** | | | **Removal of roundwood** | | |
|---|---|---|---|---|---|
| **Amount in 1990** | **Amount in 2015** | **Yearly increase** | **Total amount in 2017** | **For fuelwood in 2017** | **For other purposes in 2017** |
| $1.3×10^9$ m$^3$ | $1.9×10^9$ m$^3$ | 1.5% | $15 ×10^6$ m$^3$ | $4.85×10^6$ m$^3$ | $10.15×10^6$ m$^3$ |

Source: Bioenergy Europe (2019).

A fuelwood quantity of $4.85×10^6$ m$^3$, assuming a wood density of $d_{wood} = 0.53$ t/m$^3$ for Douglas fir (The Engineering ToolBox, 2024), corresponds to 2,570 kilotons (denoted as $M_{wood}$). Douglas fir is a significant species in forestry and is commonly used in construction for lumber, plywood, and other materials. It has recently been recommended for wider plantation in Romania due to its resistance and resilience to drought (Mihai et al., 2022). The amount of wood required to operate a 50 MW power plant, equivalent to 157.28 kilotons per year (kt/year) (see Table 3), accounts for only 6.13% of the total wood fuel harvested in Romania in 2017.

In a generic analysis of the value chain for co-firing steam-exploded biomass (black pellets) and pulverised coal, the higher heating values (HHVs) were estimated at 25.82 MJ/kg for coal and 21.4 MJ/kg for black pellets (del Alamo & Tranås, 2019). Using these HHVs, the annual feedstock requirements ($\dot{M}_{fuel}$) for operating a 50 MW power plant can be calculated using the following formula:

$$\dot{M}_{fuel} = W_{capacity} \,/\, HHV_{fuel} \times t_{annual} \times (3600\ s/h) \times (10^{-6}\ \text{kt}/kg),$$

where: $W_{capacity} = 50$ MW, $HHV_{fuel}$ is the heating value of the fuel, and $t_{annual}$ represents the assumed annual operation time, set to $t_{annual}$ = 8,000 hrs/year. The annual feedstock requirements for coal and black pellets for a 50 MW power plant are shown in Table 2.

*Table 2. Higher heating values (MJ/kg) and annual amounts (kt/year) of fuels for a 50 MW power plant*

| Feedstock | HHV [MJ/kg] | $\dot{M}_{fuel}$ [kilotons/year] |
|---|---|---|
| Coal | 25.82 | 55.77 |
| Black pellets | 21.3 | 67.61 |

Source: Own research.

## Methodology

### *Operational cost estimation for a 50 MW power plant*

In the following analysis, two distinct value chains are evaluated to estimate the operational costs of a 50 MW fuel-input power plant: a coal-based power plant (reference case) and a black-pellet-based power plant designed for combined heat and power production. A schematic representation of the two value chains is provided in Figure 1, illustrating the combustion processes in both the black-pellet power plant (using steam-exploded woody biomass) and the traditional coal power plant. The schematic is adopted from the value chain model used in the analysis by del Alamo & Tranås (2019).

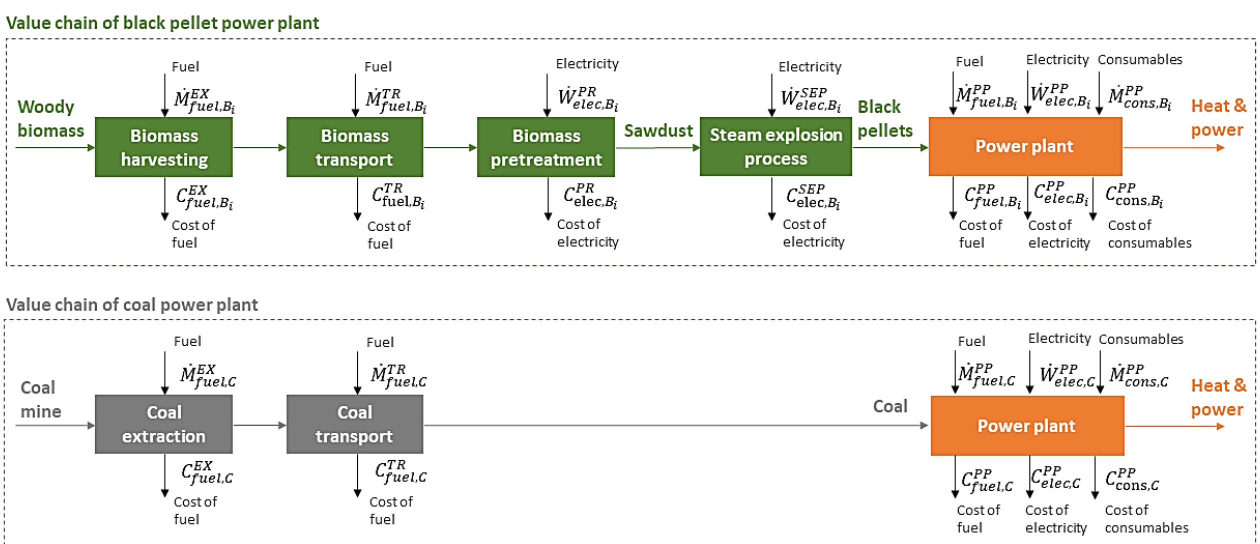


*Figure 1. Value chains for a black-pellet and a coal power plant*

Source: del Alamo & Tranås (2019)

Both value chains involve the extraction or harvesting of feedstock from the source, its transportation, and its utilisation in the power plant. Table 3 presents the estimated fuel requirements for a 50 MW plant operating 8,000 hours annually. The conversion yield from sawdust to black pellets ($y_{blackpellet}$) is estimated at 2.09 kg of sawdust per kg of black pellet, based on data from del Alamo & Tranås (2019). Additionally, the amount of wood required to produce the necessary sawdust is estimated at 157.28 kt/year, using a mass conversion yield ($y_{sawdust}$) of 1.11 kg wood per kg of sawdust from the same source. Detailed calculations are provided below:

$$\dot{M}_{blackpellet,B_i} = \dot{M}_{sawdust,B_i} \times y_{blackpellet}$$

$$\dot{M}_{sawdust,B_i} = \dot{M}_{wood,B_i} \times y_{sawdust}$$

*Table 3. Estimation of annual fuel amount for coal based and black pellet-based power plants*

| **Coal power plant** | | **Black pellet power plant** | |
|---|---|---|---|
| Coal amount (kt/year) | 55.77 | Black pellet amount [kt/year] | 67.61 |
| | | Sawdust amount [kt/year] | 141.55 |
| | | Wood amount [kt/year] | 157.28 |

Source: data from del Alamo & Tranås (2019).

Tables 4 and 5 present comprehensive lists of the parameters and variables used in the value chain model for power production based on black pellets and coal. Table 4 details the parameters along with their applied values in the current study, while Table 5 lists the variables calculated by the model.

*Table 4. List of parameters for the black pellets and coal value chains*

| Parameter | Symbol | Value |
|---|---|---|
| Higher heating value of coal | $HHV_{coal}$ | 25.82 MJ/kg |
| Higher heating value of black pellet | $HHV_{blackpellet}$ | 21.3 MJ/kg |
| Wood to sawdust mass yield | $y_{sawdust}$ | 1.11 kg wood/kg sawdust |
| Sawdust to black pellet mass yield | $y_{blackpellet}$ | 2.09 kg sawdust/kg black pellet |
| Density of wood – Douglas fir | $d_{wood}$ | 0.53 t/ m$^3$ |
| Diesel consumption of chain saw | $m_{diesel,wood}$ | 2 litres/m$^3$ |
| Cost of diesel | $c_{diesel}$ | 6.75 RON/litre |
| Diesel consumption of the truck | $m_{diesel,truck}$ | 0.3 litre/km |
| Load capacity of the truck | $m_{load,truck,B_i}$ | 12 t/shipment |
| Average transport distance from biomass source to the plant | $L_{wood,Bi}$ | 200 km/shipment |
| Cost of electricity | $c_{elec}$ | 0.47 RON/kWh |
| Specific electricity consumption for log debarking and milling | $w_{elec,B_i}^{dm}$ | 36.7 kWh/t |
| Specific electricity consumption for sieving | $w_{elec,B_i}^{s}$ | 7 kWh/t |
| Specific electricity consumption for dust receiving and scalping | $w_{elec,B_i}^{rc}$ | 1.5 kWh/t |
| Specific electricity consumption for pre-drying | $w_{elec,B_i}^{predry}$ | 15 kWh/t |
| Specific electricity consumption for dust screening and sieving | $w_{elec,B_i}^{ss}$ | 4 kWh/t |
| Specific electricity consumption for dried dust milling | $w_{elec,B_i}^{dmill}$ | 11 kWh/t |

| Parameter | Symbol | Value |
|---|---|---|
| Specific electricity consumption for steam explosion unit | $w_{elec,B_i}^{SEU}$ | 25 kWh/t |
| Specific electricity consumption for post-drying | $w_{elec,B_i}^{postdry}$ | 26 kWh/t |
| Specific electricity consumption for black pellets milling | $w_{elec,B_i}^{bpmill}$ | 4 kWh/t |
| Specific electricity consumption for pelleting | $w_{elec,B_i}^{pellet}$ | 103 kWh/t |
| Fuel oil used in auxiliary burners of black pellet power plant | $m_{fuel,B_i}^{PP}$ | 0.06 litres/GJ input fuel |
| Specific ammonia consumption in power plant | $m_{ammonia,B_i}^{PP}$ | 5.44 litres/t input fuel |
| Specific water consumption in power plant | $m_{water,B_i}^{PP}$ | 715.5 litres/t input fuel |
| Specific limestone consumption in power plant | $m_{limestone,B_i}^{PP}$ | 34.74 kg/t input fuel |
| Cost of ammonia | $c_{ammonia}$ | 7.74 RON/litre |
| Cost of water | $c_{water}$ | 0.23 RON/m$^3$ |
| Cost of limestone | $c_{limestone}$ | 178.5 RON/t |
| Efficiency for nominal power production | $\eta_{nom}$ | 33% |
| Efficiency for net power production | $\eta_{net}$ | 30% |
| Plant capacity | $W_{capacity}$ | 50 MW |
| Specific cost of coal extraction | $c_{coal,C}^{EX}$ | 173.85 RON/t |
| Load capacity of truck for coal transport | $m_{load,truck,C}$ | 32 t/shipment |
| Average transport distance from coal source to power plant | $L_{coal,C}$ | 90 km |
| Fuel oil used in auxiliary burners of coal power plant | $m_{fuel,C}^{PP}$ | 0.06 litres/GJ input fuel |
| Specific ammonia consumption in power plant | $m_{ammonia,C}^{PP}$ | 5.44 litres/t input fuel |
| Specific water consumption in power plant | $m_{water,C}^{PP}$ | 715.5 litres/t input fuel |
| Specific limestone consumption in power plant | $m_{limestone,C}^{PP}$ | 34.74 kg/t input fuel |

Source: Own research.

*Table 5. List of variables for the black pellets and coal value chains*

| Variable | Symbol |
|---|---|
| Annual amount of wood | $\dot{M}_{wood,B_i}$ |
| Fuel required for biomass harvesting | $\dot{M}_{fuel,B_i}^{EX}$ |
| Operational cost of biomass harvesting | $C_{fuel,B_i}^{EX}$ |
| Fuel required for biomass transport | $\dot{M}_{fuel,B_i}^{TR}$ |
| Operational cost of biomass transport | $C_{fuel,B_i}^{TR}$ |
| Operational cost of biomass pretreatment | $C_{elec,B_i}^{PR}$ |
| Total electricity consumption of biomass pretreatment | $\dot{W}_{elec,B_i}^{PR}$ |
| Total electricity consumption of steam explosion process | $\dot{W}_{elec,B_i}^{SEP}$ |
| Operational cost of steam explosion process | $C_{elec,B_i}^{SE}$ |
| Annual amount of sawdust | $\dot{M}_{sawdust,B_i}$ |

| Variable | Symbol |
|---|---|
| Annual amount of black pellet | $\dot{M}_{blackpellets,B_i}$ |
| Operational cost of black pellet powered power plant | $C^{PP}_{blackpellet,B_i}$ |
| Internal power consumption of power plant | $\dot{W}^{PP}_{elec,B_i}$ |
| Amount of fuel oil used in auxiliary burners | $\dot{M}^{PP}_{fuel,B_i}$ |
| Cost of consumables | $C^{PP}_{cons,Bi}$ |
| Operational cost of coal extraction | $C^{EX}_{coal,C}$ |
| Operational cost of coal transport | $C^{TR}_{fuel,C}$ |
| Fuel required for coal transport | $\dot{M}^{TR}_{fuel,C}$ |
| Operational cost of coal-fired power plant | $C^{PP}_{coal,C}$ |
| Internal power consumption of coal power plant | $\dot{W}^{PP}_{elec,C}$ |
| Annual amount of coal | $\dot{M}_{coal,C}$ |
| Internal power consumption of power plant | $\dot{W}^{PP}_{elec,C}$ |
| Amount of fuel oil used in auxiliary burners | $\dot{M}^{PP}_{coal,C}$ |
| Cost of consumables | $C^{PP}_{cons,C}$ |

Source: Own research.

*Biomass harvesting*

Biomass harvesting involves cutting trees using diesel-powered chain saws. According to Ghaffariyan et al. (2018), the diesel consumption for wood cutting is estimated at $m_{diesel,wood}$ = 2 litres/m$^3$. The cost of diesel is set at $c_{diesel}$ = 6.75 RON/l, based on the average cost for July 2023 (EUENERGY, 2024). The costs associated with biomass harvesting are assumed to be solely due to diesel consumption, calculated as:

$$C^{EX}_{fuel,B_i} = \dot{M}^{EX}_{fuel,B_i} \times c_{diesel},$$

where the fuel required for biomass harvesting is given by:

$$\dot{M}^{EX}_{fuel,B_i} = \dot{M}_{wood,B_i} \times m_{diesel,wood} \ / \ d_{wood}.$$

Here, $d_{wood}$ is the density of dry wood, assumed to be $d_{wood}$ = 0.53 t/m$^3$ for Douglas Fir, as used in this work (The Engineering Toolbox, 2024).

*Biomass transport*

Biomass transport involves moving the harvested biomass to a pretreatment facility. The transport is assumed to be conducted using diesel-powered trucks. The transport costs, $C^{TR}_{fuel,B_i}$, are based on diesel consumption and are calculated as:

$$C^{TR}_{fuel,B_i} = \dot{M}^{TR}_{fuel,B_i} \times c_{diesel},$$

$$\dot{M}^{TR}_{fuel,B_i} = \dot{M}_{wood,B_i} \times m_{diesel,truck} \times L_{wood,Bi} \ / \ m_{load,truck},$$

where $\dot{M}^{TR}_{fuel,B_i}$ is the annual diesel consumption for transport, $m_{diesel,truck}$ is the diesel consumption rate of the truck (0.3 litres/km (SMMT, 2023), $m_{load,truck,B_i}$ is the load capacity of the truck (12 tons/shipment[1]), and $L_{wood,Bi}$ is the average transport distance from the biomass source to the plant (200 km/shipment[2]).

*Biomass pretreatment*

Biomass pretreatment involves producing sawdust from wood through processes such as log debarking, milling, and sieving. The costs associated with pretreatment arise from electricity consumption, with the cost of electricity set at $c_{elec}$ = 0.47 RON/kWh for Romania, based on the average rate from August 2023 (EUENERGY, 2024). The operational cost of biomass pretreatment is calculated as:

$$C_{elec,B_i}^{PR} = \dot{W}_{elec,B_i}^{PR} \times c_{elec},$$

where $\dot{W}_{el,B_i}^{PR}$ represents the total electricity consumption of biomass treatment, given by:

$$\dot{W}_{el,B_i}^{PR} = \dot{M}_{wood,B_i}\left(w_{elec,B_i}^{dm} + w_{elec,B_i}^{s}\right).$$

Here, $w_{elec,B_i}^{dm}$ is the specific electricity consumption for log debarking and milling (36.7 kWh/t), and $w_{elec,B_i}^{s}$ is the electricity consumption for sieving (7 kWh/t) (del Alamo & Tranås, 2019).

*Steam explosion process*

Steam explosion converts sawdust into black pellets, with associated costs primarily arising from electricity consumption across various processing stages (measured in kWh per ton of input solid feedstock). The energy requirements for each stage are as follows (del Alamo & Tranås, 2019):

- Dust receiving and scalping, $w_{elec,B_i}^{rc}$: 1.5 kWh/t
- Pre-drying, $w_{elec,B_i}^{predry}$: 15 kWh/t
- Dust screening and sieving, $w_{elec,B_i}^{ss}$: 4 kWh/t
- Dried dust milling, $w_{elec,B_i}^{dmill}$: 11 kWh/t
- Steam explosion unit, $w_{elec,B_i}^{SEU}$: 25 kWh/t
- Post-drying, $w_{elec,B_i}^{postdry}$: 26 kWh/t
- Black pellets milling, $w_{elec,B_i}^{bpmill}$: 4 kWh/t
- Pelleting, $w_{elec,B_i}^{pellet}$: 103 kWh/t

[1] Private communication with a Romanian company.

The operational cost of the steam explosion process is calculated as follows:

$$C_{elec,B_i}^{SE} = \dot{W}_{elec,B_i}^{SEP} \times c_{elec},$$

$$\dot{W}_{elec,B_i}^{SEP} = \dot{M}_{sawdust,B_i}(w_{elec,B_i}^{rc} + w_{elec,B_i}^{predry} + w_{elec,B_i}^{ss} + w_{elec,B_i}^{dmill} + w_{elec,B_i}^{SEU} + w_{elec,B_i}^{postdry} + w_{elec,B_i}^{bpmill} + w_{elec,B_i}^{pellet}),$$

where $\dot{W}_{elec,B_i}^{SEP}$ represents the total annual electric power consumed in the steam explosion process, and $\dot{M}_{sawdust,B_i}$ is the annual quantity of sawdust used, measured in kt/year.

*Black pellet combustion power plant*

The costs associated with power production using black pellets, denoted $C_{blackpellet,B_i}^{PP}$, arise from several factors, including utility usage, internal power consumption, and consumable materials. Specifically, these costs include:

- Fuel oil used in auxiliary burners, $m_{fuel,B_i}^{PP}$: 0.06 litres/GJ input fuel
- Internal power consumption $\dot{W}_{elec,B_i}^{PP}$, calculated as the difference between nominal and net power production
- Consumables (del Alamo & Tranås, 2019):
  - Ammonia, $m_{ammonia,B_i}^{PP}$: 5.44 litres/ton input fuel
  - Process water, $m_{water,B_i}^{PP}$: 715.5 litres/ton input fuel
  - Limestone, $m_{limestone,B_i}^{PP}$: 34.74 kg/ton input fuel

The costs of ammonia, water, and limestone are as follows[2]: $c_{ammonia}$ = 7.74 RON/litre, $c_{water}$ = 0.23 RON/m$^3$, and $c_{limestone}$ = 178.5 RON/ton, respectively. The operational cost of a power plant powered by black pellets is calculated as:

$$C_{blackpellet,B_i}^{PP} = \dot{M}_{fuel,B_i}^{PP} \times c_{diesel} + \dot{W}_{elec,B_i}^{PP} \times c_{elec} + C_{cons,B_i}^{PP},$$

where

$$\dot{M}_{fuel,B_i}^{PP} = m_{fuel,B_i}^{PP} \times \dot{M}_{blackpellet,B_i} \times HHV_{blackpellet}$$

$$C_{cons,B_i}^{PP} = \dot{M}_{blackpellet,B_i}\left(m_{ammonia,B_i}^{PP} \times c_{ammonia} + m_{water,B_i}^{PP} \times c_{water} + m_{limestone,B_i}^{PP} \times c_{limestone}\right),$$

$$\dot{W}_{elec,B_i}^{PP} = W_{capacity}\,(\eta_{nom} - \eta_{net}).$$

Here, $C^{PP}_{cons,B_i}$ is the cost of consumables, $\dot{M}^{PP}_{fuel,B_i}$ is the annual amount of fuel oil used in auxiliary burners, $\dot{M}_{blackpellet,B_i}$ is the annual amount of black pellets, $W_{capacity}$ is the plant capacity (50 MW), and $\eta_{nom}$ (33%) and $\eta_{net}$ (30%) are the applied efficiencies for nominal and net power production, respectively.

***Operational cost for the value chain of a coal power plant***

*Coal extraction*

Coal extraction involves mining activities, with the operational costs given as $c^{EX}_{coal,C}$ = 173.85 RON/ton coal (Boca, 2011). The total cost of coal extraction, $C^{EX}_{coal,C}$, is calculated as:

$$C^{EX}_{coal,C} = \dot{M}_{coal,C} \times c^{EX}_{coal,C},$$

where $\dot{M}^{EX}_{coal,C}$ represents the annual amount of coal extracted.

*Coal transport*

The transport of coal involves moving the extracted coal to the power plant using diesel-powered trucks. The cost of transport, $C^{TR}_{fuel,C}$, is calculated as:

$$C^{TR}_{fuel,C} = \dot{M}^{TR}_{fuel,C} \times c_{diesel},$$

$$\dot{M}^{TR}_{fuel,C} = \dot{M}_{coal,C} \times m_{diesel,truck} \times L_{coal,C} \,/\, m_{load,truck,C},$$

where $\dot{M}^{TR}_{fuel,C}$ is the annual diesel consumption, $m_{load,truck,C}$ is the load capacity of a truck for coal transport (32 ton/shipment[2]), and $L_{coal,C}$ is the average transport distance from the coal source to the power plant (90 km). The distance is based on the estimated distance between the Hunedoara coal mine and the Paroșeni power station in Romania.

*Coal combustion power plant*

The costs associated with power production from coal, $C^{PP}_{coal,C}$, arise from the use of utilities, including:

- Fuel oil for auxiliary burners, $m^{PP}_{fuel,C}$: 0.06 litres/GJ input fuel
- Internal power consumption, $\dot{W}^{PP}_{elec,C}$
- Consumables $C^{PP}_{cons,C}$ such as (del Alamo & Tranås, 2019):
  - Ammonia, $m^{PP}_{ammonia,C}$: 5.44 litres/ton input fuel
  - Process water, $m^{PP}_{water,C}$: 715.5 litres/ton input fuel
  - Limestone, $m^{PP}_{limestone,C}$: 34.74 kg/ton input fuel

The operational cost for a coal-fired power plant is calculated as:

$$C^{PP}_{coal,C} = \dot{M}^{PP}_{fuel,C} \times c_{diesel} + \dot{W}^{PP}_{elec,C} \times c_{elec} + C^{PP}_{cons,C}$$

$$\dot{M}^{PP}_{fuel,C} = m^{PP}_{fuel,C} \times \dot{M}_{coal,C} \times HHV_{coal}$$

$$C^{PP}_{cons,C} = \dot{M}_{coal,C}(m^{PP}_{ammonia,C} \times c_{ammonia} + m^{PP}_{water,C} \times c_{water} + m^{PP}_{limestone,C} \times c_{limestone})$$

$$\dot{W}^{PP}_{elec,C} = W_{capacity}\ (\eta_{nom} - \eta_{net}),$$

where $W_{capacity}$ is the plant capacity (50 MW), $\dot{M}^{PP}_{fuel,C}$ is the annual consumption of fuel oil for auxiliary burners, and $\eta_{nom}$ and $\eta_{net}$ are the efficiencies for nominal and net power production, respectively.

***Operational cost comparison between black pellet and coal power plants***

Estimates of the operational costs across each stage of the power production value chain using black pellets and coal are presented in the table below.

*Table 6. Operational costs for the value chain of power produced from black pellets and coal*

| | | **Black pellets value chain [million RON/year]** | **Coal value chain [million RON/year]** |
|---|---|---|---|
| Harvesting/extraction | | 70.77 | 9.70 |
| Transport | | 5.3 | 0.3 |
| Pretreatment | | 3.23 | n/a |
| Steam explosion | | 12.61 | n/a |
| Power production | Fuel | 0.58 | 0.58 |
| | Electricity | 4.90 | 4.90 |
| | Consumables | 3.28 | 2.70 |
| TOTAL | | 100.68 | 18.18 |

Source: Own research.

The total operational cost for power production using black pellets is 100.68 million RON/year, which is over five times higher than the cost for coal, totalling 18.18 million RON/year. This significant cost disparity primarily stems from the harvesting/extraction phase, as biomass harvesting is more expensive than coal mining. Additionally, due to the lower heating value of black pellets, larger volumes are required to meet the plant's energy capacity, leading to higher transportation costs as well.

The black pellet value chain also includes additional biomass processing steps, such as pretreatment and steam explosion, which both require electricity. Fuel for auxiliary burners and internal power consumption are defined per MJ fuel, so the associated costs are the same for both value chains. However, consumable costs, which are based on per-ton fuel consumption, are higher for black pellets, resulting in greater expenses in this area.

A further consideration is the difference in ash content between black pellets and coal. Although ash disposal could affect total costs, this factor was not included in the calculations due to a lack of local data from Romania.

***Quantitative effects on Romanian energy sector and GDP growth***

This section presents the quantitative effects of using black pellets for power production on the energy sector and Gross Domestic Product (GDP) growth. The impact on the energy sector is assessed by comparing the total potential power production from black pellets produced from wood with the total power generation in Romania.

As previously noted, operating a 50 MW power plant using black pellets requires 157.28 kilotons of wood annually. According to data from 2017, Romania harvested a total of 2,570 kilotons of roundwood for fuel. If all harvested wood were utilised, it could potentially yield 817 MW, translating to an annual output of 6,536,114 MWh, assuming 8,000 hours of operation.

In 2016, Romania produced 61,784,600 MWh electricity (Worldometer, 2023). Thus, if black pellet-powered power plants were fully operational, they could account for approximately 10.57% of the total electricity generated. In contrast, biomass represented only 0.8% of the installed power capacity in Romania as of August 2023 (The International Trade Administration, 2023). This indicates a potential tenfold increase in biomass utilisation for energy production.

Furthermore, this shift towards biomass could significantly reduce greenhouse gas emissions from the power sector, as biomass is regarded as a carbon-neutral fuel. A recent study by Birgen and Sannan (2024) estimated $CO_2$ emissions for power production using the black pellets value chain at 16.27 kt $CO_2$/year, compared to 272.10 kt $CO_2$/year for the coal value chain at the same 50 MW plant capacity. Consequently, increasing the share of biomass in the energy mix is likely to lead to a significant decrease in overall emissions.

## Conclusions

A value chain analysis was conducted to evaluate the potential of using black pellets as an alternative to coal for energy production in Romania. This included an overview of black pellets producers in the country and an assessment of biomass feedstock availability. The analysis revealed that the biomass production landscape in Romania has become increasingly competitive due to rising demand and the growing number of pellet producers competing for raw materials. This competition has been further intensified by a decline in wood processing and exploitation activities in recent years, mainly due to reduced access to forest resources, legislative instability, and bureaucratic obstacles. The findings indicated that Romania officially harvests 19 million cubic meters of wood annually, utilising only 50% of its sustainable potential exploitation rate, defined as the growth rate of its forests.

In the second phase of this research, a value chain assessment was performed. Operating costs for both the black pellet and coal value chains were estimated. The operational cost for the black pellet value chain was 100.68 million RON/year, more than five times higher than the cost for coal, which was calculated at 18.18 million RON/year. This significant difference is primarily attributed to the extraction phase, as biomass harvesting is generally more expensive than coal mining. The black pellet value chain includes their production from biomass, which involves pretreatment and steam explosion processes that require electricity and incur additional costs.

It is also important to note the significant difference in ash content between these two fuels, which impacts total costs due to ash disposal expenses. However, local data from Romania on this aspect was unavailable at the time of the study and thus was not included in the calculations. Another key factor is the higher $CO_2$ emissions in the coal value chain, which further strengthens the economic advantages of utilising black pellets for energy production.

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Iceland Liechtenstein Norway grants    Norway grants

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